MODERN
BITUMINOUS ROADS AND PAVEMENTS

BY

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A THESIS

PRESENTED BY

THOMAS CECIL FORD

TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF CHEMICAL ENGINEER

1913

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MODERN BITUMINOUS ROADS AND PAVEMENTS

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Perhaps no other subject, today, has such a genuine interest in the minds of the public as that of good roads. All over the United States as well as other nations, the people are awakening to the fact that good roads are essential to the rapid growth and development of the country. The ease and comfort of travel on highways are only acquired by improvement of the roadways.

The national government has a department devoted wholly to the advancement and aid in road building. Nearly every state in the union has a highway department which looks after the building and maintaining of its roads. Every city has a department which is devoted to the improvement and maintenance of its streets and pavements. Millions of dollars are spent annually and yet the demand for more and better roads is rapidly increasing.

Up to the present time the United States Office of Public Roads has devoted its efforts to the aid of state and country work in demonstrative and advisory way but recently there was a bill introduced in Congress which provides for the building and maintaining of a system of National Highways

to be built and maintained by the national government. This system of roads would connect all the state capitols and cities of over 20,000 inhabitants. It would require 18,000 miles of roads at a cost of about 270,000,000 dollars.

Numerous societies have been organized for the advancement of the good road movement, among which are, "The Permanent International Road Congress", "The American Highway Association", "American Road Builders Association", "American Automobile Association", "American Association for the Standardization of Paving Specifications", "American Society for Municipal Improvements", and others.

The highway problems have for several years been attacked along scientific lines until road building has now become a science and an art.

Specifications for the same classes of roads and pavements in different cities and states have varied so that an attempt has been made to standardize them and thus get better and more uniform results at a less expense. This work has been done largely by the American Association for the Standardization of Paving Specifications and the American Society for Municipal Improvement.

There are many types of construction of roads and

pavements which might be of interest but only those in which bituminous materials are used will be considered here.

The first bituminous pavements in this country were laid in Brooklyn in 1867. This pavement was a mixture of broken stone, gravel, ashes and tar. Soon after similar pavements were laid in Washington, D.C. and other towns with more or less success. In 1878 Trinidad asphalt was used in paving Delaware Ave., Buffalo, N.Y.; Newark, N.J.; New York City and Washington,D.C. soon followed in the use of asphalt and from then until now its use has increased with surprising rapidity until there are now many million square yards of pavement in the U.S. laid with various kinds of asphalt, which have been produced to meet the great demand for it.

Bituminous pavements may be classified as follows:-

Sheet Asphalt

Asphalt Block

Asphaltic Concrete

Asphalt Macadam

Bituminous Surfaces

A Sheet Asphalt pavement is one consisting of a mixture of sand, dust and asphalt cement in varying proportions, spread on a firm foundation and rolled to an even surface. Usually the pavement is laid in two courses; the first or binder course, consisting of a mixture of broken stone, with sometimes a little sand and asphalt cement. The thickness of the binder course varies from an inch to an inch and a half. The surface or top course as described above varies from one and a half to two inches in thickness.

The foundation for all pavements should be firm and even. The surface and under-drainage should be ample to take care of all surplus water and thus insure the pavement against its damaging effects, which are principally the weakening of the foundation and the disintigration of the bituminous mixture from the emulsifying effect on the asphalt cement. This latter effect is much more noticeable with some asphalts, such as Trinidad, than others. For sheet asphalt nothing but a good concrete foundation should be used. Any sinking or giving of the foundation will cause defects in the surface which are difficult to repair.

Every material entering into a paving mixture should be tested before its use. The sand, stone and dust comprising the mineral aggregate are tested for grading which

consists in separating into different sizes by means of screens. The grading of the binder aggregate is not so important as that of the topping. The following are the limits given by the American Society for Municipal Improvements:-

Passing	10 mesh	10 - 35 %
"	2 "	10 - 35 %
"	1 "	20 - 60 %
"	1¼ "	15 - 55 %

The quality and grading of the sand used in a top mixture is more important because it constitutes approximately 78 % of the mix. The following standard gradings are given by Richardson:-

		Heavy Traffic		Light Traffic	
Passing	200 mesh	0.0)		0.0)	
"	100 "	17.0)	34%	10.0)	20.0%
"	80 "	17.0)		10.0)	
"	50 "	30.0)		30.0)	
"	40 "	13.0)	43%	15.)	45.0%
"	30 "	10.0)		15)	
"	20 "	8.0)	23%	10)	35.0%
"	10 "	5.0)		10)	

In practical construction it is seldom that a sand or combination of sands can be obtained, at a reasonable cost, that will conform strictly to the above gradings but it is

well to keep as near these limits as possible.

Richardson gives the following analyses as standards for top mixtures:-

	Heavy Traffic	Light Traffic
Bitumen	10.5%	10.0%
Passing 200 mesh.	13.0%	10.0%
" 100 "	13.0%	9.0%
" 80 "	13.0%	9.0%
" 50 "	23.5%	26.0%
" 40 "	11.0%	12.0%
" 30 "	8.0%	10.0%
" 20 "	5.0%	8.0%
" 10 "	3.0%	6.0%

To give an idea of how nearly these standards may be followed, typical analyses of mixes used by the writer, are given below:

	Bitumen	200	100	80	50	40	30	20	10	Total
Guthrie, Okla.	10.0	9.8	11.1	9.6	30.9	9.6	9.0	7.0	3.0	100
Sapulpa, "	10.2	11.2	15.6	7.5	28.5	10.0	12.0	3.0	2.0	100
St Louis, Mo.	10.3	11.4	6.0	17.0	35.0	5.3	6.0	5.0	4.0	100
Titusville, Pa.	10.0	8.0	7.0	17.0	34.0	7.0	8.0	5.0	4.0	100
Montreal, Can.	10.0	9.0	9.3	11.5	30.2	10.6	10.2	7.2	2.0	100
Victoria, B.C.	10.5	6.7	12.7	7.4	23.2	16.9	7.4	7.5	7.7	100
Spokane, Wash.	11.0	10.0	18.0	10.0	19.0	7.0	10.0	8.0	7.0	100
Wheeling, W.Va.	9.0	5.0	2.0	2.0	15.0	14.0	24.0	10.0	19.0	100
Standard	10.0	10.0	9.0	9.0	26.0	12.0	10.0		6.0	100

With each of the above mixtures most results have been obtained. Some of the pavements have been four years with no repairs. The mixture at Wheeling, W. Va. is hardly to be recommended, and just how well it will wear is a question as

it has been down less than a year but is now in excellent condition.

The amount of asphalt cement used in a pavement mixture depends on the kind and quality of; first, the asphalt cement; second, the sand and third, the filler or dust. All other things being equal the specific gravity of the materials is the basis upon which the percentage of the ingredients of the mixture is determined. In other words the ingredients should be used according to a percentage by volume rather than by weight. Considering the same aggregate it will take less asphalt cement by weight to cover every particle with the same thickness of asphalt using one having a specific gravity of .980 than it will without having a specific gravity of 1.07. If the same asphalt cement be used with two different aggregates having the same grading and a different specific gravity, then the one having the greater specific gravity will require the lesser percentage of asphalt by weight because the surface per unit weight is less. The purity of the asphalt cement also effects the amount to be used. If an asphalt cement has a purity, i.e. bitumen soluble in carbon disulphide, of 99.5 % it will require less than one having only 56.0 % bitumen.

These differences are shown clearly by the following table:-

		% Purity of Asphalt	No. lbs. Bitumen per ton	Gravity of pure bitumen	Cu. ft. p. ton.	Sq. Yds. 2"Top Laid p.t
Various Grades of Asphalt	1-	99.5	1990	.980	32.5	98
	2-	56.0	1120	1.071	16.7	51
	3-	94.5	1890	1.068	28.3	86
	4-	71.0	1420	1.086	20.9	63
	5-	99.5	1990	1.050	30.3	92
	6-	99.5	1990	1.045	30.5	92

The quality and grading of the sand are very important factors in determining the amount of asphalt cement to be used in a mix. If a sand is hard and smooth grained it will not carry as much asphalt as if it were softer and more porous, without producing a "sloppy" mixture, i.e. one in which the asphalt will flush to the top of a load after a little jarring. The river and lake sands are usually smoother and more rounded than the bank sands; due to the scrubbing and grinding action of the water. The bank sands seem to have a more porous surface probably formed by a deposit of hydrosilicate about the surface of the grains. As a rule the finer the grading of the aggregate the more asphalt it will requir to produce a satisfactory mixture. In extreme cases these two factors may cause a variance of as much as 3 % in the asphalt used.

What has been said about gravity and grading of sand applies equally well to dust as it is used as a filler to decrease the voids in the sand and to increase the toughness of the mixture.

The most common fillers are limestone dust and Portland cement which have from 70% to 85% of material which will pass a 200 mesh screen. In the state of Washington and the province of British Columbia there are large deposits of very fine sand, 65 to 80 % of which will pass a 200 mesh screen. These sands have been used very successfully as a filler in sheet asphalt.

There are a number of different kinds of asphalt used in sheet asphalt work and much has been written concerning them, therefore no attempt will be made to give a description of the different crude materials but rather the sources, characteristics and qualities of the different asphalt cements which is the form in which the asphalt is used in the mixture.

An asphalt cement, A. C., is prepared by refining and fluxing with a residuum oil, a crude native asphalt or semi-asphaltic oil until the residue has a penetration between 45 and 100 when tested at 25° C. for 5 seconds with a No·2 needle weighted with 100. grame.

Table no.1 gives the analyses of different asphalt cements as prepared and used by the leading companies of the United States in 1912. Included in this table are the following asphalt cements: Pioneer, , Bermudez, Trinidad, Texaco, California, Cuban and Aztec. Pioneer is Utah Gilsonite, a crude native asphalt,

fluxed with a specially prepared flux. Bermudez is a natural asphalt, from a lake in Venezula, fluxed with a heavy residuum oil. Trinidad is also a native asphalt, from a lake deposit in the Island of Trinidad, fluxed with a residuum oil. Texaco is an oil asphalt prepared by distilling a crude Texas oil until the residue has the proper consistency. California is another oil asphalt prepared the same as Texaco but from crude California oil. Aztec has just been introduced on the market within the last two years and its value as a paving cement is questionable yet as it has had no service tests. It is prepared from a crude Mexican oil of which there is an abundant supply.

TABLE NO. I

Material	Pioneer A.C.	Bermudez A.C.no.2.	Trinidad A.C.
Specific Gravity	.9930	1.0760	1.2880
Melting Point	77° C.	61° C.	62.5° C.
Flash Point (C.T.)	195° C.		305° C.
Ductility 0° C.	3 cm.	0 cm.	8 cm.
" 25° C.	6 cm.	40 cm.	36 cm.
Penetration 0° C. 200 gr.1min.	47	12	12
" 25° C. 100 gr.5 sec.	78	50	50
" 46° C. 50 gr.5 sec.	206	280	285
Lose 170° C. 5 hrs.	1.2%	3.3%	2.3%
Penetration Residue 25° C.	58	21	21
Soluble in CS_2	99.77	94.15%	64.94%
Organic matter insoluble	.12	1.80 %	5.33 %
Ash	.22	4.05 %	29.73 %
Soluble in CCl 4	99.60	94.25%	65.58%
" "2 88° Beaume Naptha	71.53	70.17%	46.13%
Fixed Carbon	9.43	10.21%	5.87%

Material	Texaco A.C.	California A.C.	Cuban A.C.	Aztec A.C.
Specific Gravity	1.2880	1.0453	1.0933	1.0455
Melting Point	64° C.	59°	61°	67°
Flash Point (C.T.)	232° C.		215°	265°
Ductility 0° C.	3 cm.	0 cm.	4 cm.	0 cm
" 25° C.	21 cm.	100 cm	28 cm.	65 cm
Penetration 0° C.200 gr.1 min.	25	13	23	18°
" 25° C.100 gr.5 sec.	55	70	68	54°
" 46° C. 50 gr.5 sec.	200	320	242	290
Lose 170° C. 5 hrs.	.25%	1.4%	.3%	0.0%
Penetration Residue 25° C.	38	27	47	37
Soluble in CS	99.65%	99.58%	89.38%	99.60%
Organic Matter Insoluble	.10 %	.22%	11.78%	.25%
Ash	.25 %	.20%	8.94%	.15%
Soluble in CCl 4	99.70%	99.60%	89.11%	88.75%
" "2 88° Beaume Naptha	74.00%	76.00%	67.68%	68.86%
Fixed Carbon	9.84%	11.66%	9.70%	15.54%

Pioneer is Utah Gisonite fluxed with a special oil.
Bermudez is a solid native bitumen fluxed with a residuum oil.
Trinidad is a solid native bitumen fluxed with a residuum oil.
Texaco is an oil asphalt prepared from crude Texas oil.
California is an oil asphalt prepared from crude California oil.
Cuban is a solid native bitumen fluxed with a residuum oil.
Aztec is an oil asphalt prepared from crude Mexican oil.

No attempt will be made to give a description of the methods used in making the above tests as a complete and detailed description may be found in Bulletin no. 38 of the U.S.O.P.R.

The principal uses of the specific gravity test are its aid in identifying the asphalt and in determining the percentage to be used in a mixture as described above. It is sometimes used as a method of control in the preparation of bituminous materials It does not however indicate the value of a paving cement as has been the contention of some engineers.

The melting point of an A.C. is a very important consideration in determining its suitability for use in a paving mixture. It will be noted from the table, No. 1, that the melting points are fairly uniform with the exception of Pioneer which is considerable higher. Upon carefull examination of numerous pavements laid with these various materials it was found that those with the lower melting point were much more affected by the summer heat, getting soft and marking badly under traffic, while during the cold winter weather they became very hard and slippery. The material with the higher melting point did not show these effects nearly so much. Of course the susceptibility to temperature changes as shown by the different penetrations bring out these characteristics more clearly. It is not advisable to have too high a melting point though for this makes the material much harder to handle and requires a higher temperature of the

mixture which, of course, adds to the cost.

The penetration test is one of the most valuable in deciding upon the proper quality of the asphalt to be used. This test is made at three different temperatures as follows:

1. 0° C. No. 2 needle weighted with 200 grams for 1 minute.
2. 25° C. " " " " 100 " " 5 seconds
3. 45° C. " " " " 50 " " 5 "

The first test is used to determine the proper consistency at which the A.C. is to be used and is a means of control in its preparation. If any one refined asphalt be fluxed to a certain consistency then all the other chemical and physical properties will change proportionately so that the one test is all that is necessary to make after complete analysis has been made at that consistency. The three tests combined are used to determine the susceptibility to temperature changes, which has a great bearing upon the characteristics of the pavement. A pavement laid with an A.C. which has a high ratio between the penetration at 0° C. and 45° C. will become very soft and will mark badly during the hot summer months, and in the cold winter months it will become very hard and slippery as well as noisy, while one laid with an A.C. having a low ration between the penetration at 0° C. and 45° C. will not get so soft and mark up so badly in the hot summer months nor will it get so hard, slippery or noisy in the winter months. These characteristics are very

marked in pavements laid with different materials.

The ductility test is claimed by many chemists and engineers to be a measure of the cohesiveness and cementitiousness of the asphalt and it is further claimed that a high ductility at 25° C. is essential to a good paving cement. Materials having a high ductility have a high susceptibility to temperature changes and become very hard and brittle when cold. From the above it will be noted that the materials having a high ductility at 25° C. have no ductility at 0° C., while the one having a low ductility at 25° C. has about half as much at 0° C. It is when the pavement is cold that it contracts and needs a ductile material, when it is hot it expands and does not need it.

The loss at 170° C. for 5 hrs. and the penetration of the residue at 25° C. is determined to get by a quick method some idea as to what will be the effect of time on the cement after it is in the pavement. One having a high loss would naturally be affected more than one with a low loss all other things being equal. An exceptionally high loss accompained with a low flash point would indicate that too light an oil had been used for fluxing.

The solubility in carbon disulphide gives the purity of the asphalt, which is the amount of bituminous binding material in it.

88° Beaume paraffine naptha separates the bitumen into two classes, each composed of various hydrocarbons. Those hydro-

carbons insoluble in the naptha give body and consistency to the asphalt cement, and is probably a measure of the adhesiveness. In the materials of the above table there is very little difference in the percentage soluble in 88° Beaume paraffin naptha.

When an asphalt has been overheated some of the hydrocarbons will be broken down into compounds containing a very large percentage of carbon known as carbenes. These compounds are insoluble in carbon tetrachloride but soluble in carbon disulphide so that their presence is determined by the difference in the solubility in the two solvents. It may happen in good asphalts which have not been over heated that they will be slightly more soluble in carbon tetrachloride than in carbon bisulphide. A very small percentage of carbenes will render a material unfit for use in pavements. The presence of carbenes may also be detected by a microscopic examination.

The fixed carbon is determined by an arbitrary method the same as is used in coal analysis, and gives some idea as to the proportion of the heavier hydrocarbons present. It is of most value in testing oil asphalts such as California and Mexican, for these often show a very high percentage of fixed carbon which indicates that the asphalt has been distilled too rapidly at a high temperature. 15 % should be the maximum allowable fixed carbon content.

Among the most important features of a successful bituminous pavement is the proper handling of materials both at the plant and on the street. There is no doubt but that a majority of the failures are due either to carelessness or ignorance in construction. After a proper mixture has been determined it is essential that it be kept uniform, and the temperature be kept within certain limits usually 275° F., depending on the melting point of the A.C. and the distance to be hauled. The question is often raised as to why the maximum temperature is only 375° F. when the temperature used in refining is in some cases 600° F. It is found that when the bitumen is in a thin coat around the hot particles of sand and stone that it is burned at a much lower temperature than when heated in bulk and only a small proportion exposed to the air, therefore the temperature of the mixture must be lower.

The uniformity of the ingredients in a mixture can only be obtained by the most careful supervision. It is necessary to make tests of the grading of the mineral aggregates at least three or four times a day and tests for bitumen from representative "pot" samples should be made at least twice a day.

The laying on the street consists of spreading, raking and rolling. When a load reaches the street it is dumped

from the wagon just far enough ahead of what has been laid so that the shovellers can spread it without having to carry any ahead. After spreading,it should be well raked and "combed" until it is true to grade. The raking is very important and only experienced men should be employed. The rolling is usually done with two rollers, a five ton and an eight ton. The first or surface rolling is done with the smaller roller just as quickly as the material is cold enough so that it will not blister under the roller. A water spray is used on the wheels of the roller to prevent the mixture picking up or sticking to the wheels. If the surface rolling is delayed until the mixture gets too cold it will "honeycomb" and the proper compression will not be obtained. In some cases the surface will chill so that no amount of rolling can thoroughly compress it and the pavement will be porous and absorb water, which will be shown by the surface remaining damp for a long time after a rain. When this condition exits the water will freeze and the expansion will cause the pavement to disintegrate. In one case a pavement constructed with California where this condition existed, a heavy rain, followed by freezing and thawing weather caused the asphalt which became hard and brittle to break loose from the aggregate and was washed into the gutter. The surface rolling should be followed by a thin coat of Portland

cement swept over the surface just ahead of the larger roller which is run very slowly, giving the surface a straight and double diagonal roll until it is smooth, even and free from roller marks and will show no indentation from the roller.

Sometimes the rolling will produce numerous surface craks extending from ¼ " to an 1" in depth. This may be caused by movement of the binder stone, slipping or creeping of the top on smooth concrete when no binder course is used or a burnt or dry mixture, i.e. one without sufficient A. C. in it.

An asphalt block pavement is one composed of blocks about 2" x 4" x 8" made by compressing with about 240 tons pressure a mixture of ½ " stone chips, sand, dust and A.C. An A.C. with a very low penetration usually 15, is used in making these blocks, as well as a very low percentage of bitumen. The following is a typical analysis:-

Bitumen			7.5 %
Passing	200	mesh	13.0 %
"	100	"	3.0 %
"	80	"	3.5 %
"	50	"	8.0 %
"	40	"	5.0 %
"	30	"	4.0 %
"	20	"	6.0 %
"	10	"	14.0 %
"	8	"	7.0 %
"	¼	"	22.0 %
"	½	"	7.0 %

The blocks are laid similar to brick on a concrete

foundation with about 1" cushion of a 1-3 sand cement mix fairly dry.

Asphaltic concrete is a pavement composed of a mixture of crushed stone, sand, A.C. and in some cases dust. There are three distinct types of asphaltic concrete which will be designated as Type A, B and C.

Type A is what is known as Topeka mix. This name was given it because it is the mix described in the specifications of Topeka, Kansas upon which the Warren Bros. Co. of Boston tries to get an injunction against the City on the grounds of infringement of their patent no. 665725. The court ruled that this was not an infringement and Warren Bros. signed the decree of the court acknowledging it to be correct.

The specifications for this mix are as follows:

Bitumen	7 - 11%
Mineral Aggregate	
Passing 200 Mesh	5 - 11%
" 40 "	18 - 32%
" 10 "	25 55%
" 4 "	8 - 22%
" 2 "	less than 10%

Some pavements laid under this specification are given a flush or Squeegee coat of asphalt followed by a thin coating of clean half inch crushed rock screenings or coarse torpedo sand. The purpose of the flush coat and screenings

is to fill the surface voids and seal it making it impervious to water. The screenings are worked into the flush coat by traffic until it finally has an appearance similar to sheet asphalt.

The crushed rock used should be trap, "hard heads", granite, hard limestone or any good durable stone. It is better to have the stone free from dust as it is usually distributed very uniformly which makes it difficult to get a uniform grading of the aggregate, besides this the dust is apt to form a crust about the particles of stone if it becomes wet and when dried it will not come off and when the asphalt is added it does not penetrate to the stone and thus the mixture will be apt to have loose stones which are liable to cause ravelling, i.e., picking out of the stone under traffic.

The A.C. used in this class of work is very similar to that used in sheet asphalt, in fact some companies use the same material.

In this class of construction the low ductile asphalts such as "Pioneer" is particularly well adapted especially where a flush coat is used as it does not get brittle and chip out under traffic in cold weather as the high ductile materials do. In order to overcome this ravelling some companies use a much higher percent of asphalt in the mix,

e.g., in N.Y. City last year one company used as high as 10.6% of Mexican asphalt. A sample from this work showed the following analysis:

Bitumen		10.6%
Passing	200 M	7.0%
"	80	15.0%
"	40	19.0%
"	20	20.4%
"	10	10.0%
"	¼	13.0%
"	½	5.0%

This pavement may be laid on concrete, macadam, old brick or stone as a foundation. If it is laid on macadam great care must be taken to see that there are no soft or spongy places in it, but if the macadam is good, equal if not better results may be obtained.

What has been said regarding the construction of sheet asphalt pavements applies equally well to asphaltic concrete and as this subject was discussed in some detail, it will not be repeated here.

This class of pavement has been very popular in the last two years, many thousand yards have been laid with excellent results. It is particularly well adapted to heavy automobile traffic with medium horse drawn traffic. In N.Y. City last year over 100 miles were laid. A great deal of it having a very heavy horse drawn traffic with heavy

auto traffic and a recent inspection of these pavements found them in good conditions except where there had been faulty construction.

Asphaltic concrete Type B. consists of a mixture of crushed stone varying in size from that passing a 1" ring to that retained on an 8 mesh screen and asphalt, no sand or dust being used. This type requires much less asphalt in the mixture but must have a flush coat of about ¾ gal. per square yard with a coat of screening as described under Type A.

What has been said of the quality of stone under Type A. applies equally well to Type B.

The A.C. used is much softer as shown by the following analyses:

	Pioneer	Bermudez
Specific Gravity	.9866	1.0242
Melting Point	137° F.	117° F.
Flash Point (C.F.)	430° F.	360° F.
Penetration at 0° C.	59	19
" " 25° C.	81	110
" " 45° C.	221	Too soft
Loss at 170° C. 5 hrs.	.33%	2.92%
Penetration of residue 25° C.	68	65
Solubility in C.S.₂	99.86%	97.42%
" " C C l 4	99.80%	97.88%
" " 88° Be. Naptha	73.25%	74.51%
Fixed Carbon	9.20%	9.83%

Coal tars and water gas tars have also been used for this type of pavement, particularly in the eastern states

but they are so susceptible to temperature changes and pavements laid with them get so hard and slippery that they have not been very popular. A great deal of experimental work has been done with tar asphalt mixtures. About 12 - 15 % of asphalt is the maximum that can be used safely with a tar. If an excess is used it will get "cheesey" and have no binding power. When a small percentage of asphalt is used the tars are improved because the asphalt makes them less susceptible to temperature changes and more stable. The following are typical analyses of these materials.

	Coal Tar	Water Gas Tar
Specific Gravity	1.258	1.158
Float Test @ 50° C.	2 min.30 sec.	23 sec.
Soluble in CS_2	70.4%	98.9%
Organic Matter Insoluble	29.5%	1.1%
Ash	.1%	.05%
Distillation		
Oils to 110° C.	.2%	.03%
110 - 170 "	.6%	.05%
170 - 270	10.2%	10.00%
270 - 315	7.5%	19.10%
Residue	81.4%	69.40%

Type C. is a patented pavement, similar to Types A and B. It is composed of stone such as is used in type B. and sand. This requires a little more A.C. than B. but not so much as Type A. The following are the grading limits given in the patent:-

Impalpable powder	1 - 3 %
" " to ¼"	10 - 30%
¼ and larger	50 - 80%

Below is a typical analysis of a pavement of this class.

Bitumen	6.0%
Passing 200 mesh	1.7%
" 80 "	2.5%
" 40 "	8.8%
" 10 "	35.6%
" 8 "	16.8%
" 4 "	5.2%
" 2 "	18.2%
" 1 "	5.2%

It is claimed by the patentees that the grading used gives a minimum of voids producing a maximum density and inherent stability in the pavement which can not be obtained by either Type A or B. This however has been disproved by the excellent results obtained with the other classes of pavements. Their claim that a minimum in percentage of voids can only be obtained by such a graded aggregate has also been disproved by the writer in some tests made recently in which less than 16% of voids were obtained in a mixture of one sized crusher run of stone; i.e. passing a 1" ring and retained on a ¾" ring and sand.

Asphalt pavement is a pavement constructed by what is known as the Penetration Method, and is as follows:- Upon a crushed stone foundation, similar to a water-bound macadam is spread about 3" of clean stone, which will pass a 2"ring

and be retained on a 3/4" ring and rolled to an even grade when it will be about two inches thick. Over this is spread either by pouring cans or other distributors about 1½ gallons of bituminous binder to the square yard. A thin coating of clean 3/4" crushed stone is spread over the surface and then thoroughly rolled. The excess of stone is swept off and a second pouring of about ½ gallon to the square yard is applied followed by a thin coating of clean ½" stone chips, when the pavement is again well rolled.

This is perhaps the most uncertain of any of the types of bitumunous pavements for there are so many important details which are essential that are often neglected. Only first class stone, uniform in size should be used in this class of construction. The pouring should be done with the greatest care and only after thorough rolling and when the stone is clean and dry. It is almost impossible to keep from getting the bituminous material in streaks when the pouring can is used. The Eldus, which is a hand drawn distributor has given more uniform results. Many excellent roads have been built by this method but it requires a great deal of skill and attention to get good results. One great advantage is its low first cost which is a great item on country roads where traffic is light.

The bituminous binders used in asphalt macadam are much softer than in sheet asphalt as will be seen from the following typical analysis:-

	Pioneer	Bermudez	Texaco
Specific Gravity	.969	1.0427	.9862
Melting Point	116° F	109° F	Liquid
Flash Point (CF)			
Ductility 23° C.	4 cm	34.2 cm	
" 0° C	2 cm	2.0 cm	
Penetration at 0° C	95	37	Too soft
" " 25° C	183	132	" "
" " 45° C	Too soft	Too soft	" "
Loss @ 170° 5 hrs.	2.0%	4.64%	9.0%
Penetration of residue at 25° C,	138	33	139
Solubility in C.S$_2$	99.95%	96.04%	99.5 %
" " CCl 4	99.96%	95.96%	99.4 %
" " Naptha 88° Beaume	76.25%	77.30%	82.2 %
Fixed Carbon	7.74%	10.84%	8.53%
Pariffin Scale	3.14%	.84%	.22%

All of the above tests were discussed under sheet asphalt except paraffin scale. There has been a great deal of discussion as to the value of this test and at present its value is very questionable owing to the fact that no standard method is in use by which uniform and consistant results can be obtained. A large sample divided and sent to half dozen different prominent chemists brought as many different results, varying from 1 to 5 % . In each case the same method was supposed to have been used. By slightly varying the datails of distillation results varying from 1 ½ to 4.5% were obtained by the writer, using the same apparatus and

same sample.

Bituminous surfaces are used on water-bound macadam and gravel roads. These surfaces are formed by applying a heavy residuum oil to the clean dry surface of the road and than covering with a thin coating of clean stone chips or coarse sand. These surfaces are well suited to medium automobile traffic where there is not an excess of horse drawn traffic.

The first cost of a treatment as described above is very low but it has to be repeated from twice a year to every two years depending largely on the bituminous material used and the traffic conditions.

Just recently a special material for this class of work has been on the market and has been used very successfully on water-bound macadam, brick and sheet asphalt pavements. It is similar to those used in penetration work but is exceptionally adhesive.

A waterbound macadam treated with 1/2 gallon per square yard two years ago is in excellent shape. An old brick pavement similarly treated has the appearance of a bituminous pavement. A sheet asphalt pavement which was badly cracked and had started to disintegrate was repaired by a surface treatment and is in good shape. These instances are mentioned because so many attempts along this line have failed. The

following is an analysis of this material:-

Specific Gravity	.97.42
Melting Point	117° F.
Penetration at 0° C.	62
" " 25° C.	175
" " 45° C.	Too soft
Loss at 170° C. 5 hrs.	2.44%
Penetration of residue at 25° C.	105
Solubility in CS_2	99.83%
" " CCl_4	99.80%
" " 88° Be. Naptha	79.03%
Fixed Carbon	6.79%

Many attempts have been made to get a bituminous surface to adhere to a concrete pavement but have been only partially successful. Light tars will adhere for a time but as soon as they get cold they become brittle and chip off under traffic. Asphalts have been used but traffic seems to abrase the surface of the concrete forming a fine dust which allows the bituminous surface to peel off.

In conclusion it might be said that while the intelligent use of bituminous materials in road construction is well understood by a large number of chemists and engineers there is yet room for much research and experimental work which will no doubt be done in the near future as the popularity of the bituminous pavement is so rapidly increasing.